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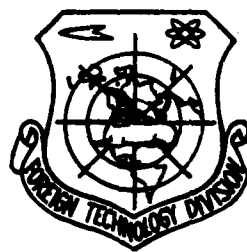
FOREIGN TECHNOLOGY DIVISION



A BRIEF HISTORY OF PHYSICS IN CHINA

by

Dai Nian-Zao



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A BRIEF HISTORY OF PHYSICS IN CHINA (Cont'd)

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MECHANICS

Although the south-pointing cart and the distance-registering cart had been in existence prior to this period, their construction had not been recorded in detail until the Sung dynasty. The chapter entitled 'Chronicle of Xing-Fu' in "History of Sung" documented the construction method of the south-pointing cart by Yian Su (960-1040) in 1027 and Wu De-Ren (dates of birth and death unknown) in 1107. The book also documented how Lu Dao-Long (dates of birth and death unknown) constructed the distance-registering cart in 1027. According to the record, the south-pointing cart was built on the basis of compound movement of various gears such as the wheel, the horizontal wheel and the axis. At the start of the cart, the finger of the wooden figure on the cart was set to point to the south and this figure would remain pointing to the south regardless of the direction the cart was traveling. As for the distance-registering cart, a set of gears of various sizes were driven by a cart wheel in such a way that one of the gears would just complete one turn and cause the wooden figure to hit a drum once whenever the cart wheel had just covered a distance of one mile. The manufacturing of this large scale machinery clearly indicated that our ancient folk had skillfully mastered the mechanical knowledge of gear systems.

Another great invention was the water driven celestial armillary station otherwise known as the astronomic clock constructed in 1092 by Su Zong (1020-1101) and Han Gong-Lian (dates of birth and death unknown). The method of construction was documented in "Summaries of New Patterns and Phenomena" by Su Zong. The book describes over 150 machine parts and contains more than 60 sketches and diagrams. The celestial armillary station had armillary, celestial image and hydraulic machinery, placing the instruments for surveying, indication and timing in an integrated wooden structural system. One of its lever installations "heavenly balance," similar to the anchor escapement in modern clocks and watches, guaranteed the constant rotation of the gear in the timing installation with respect to time. Therefore it is the forerunner

of modern clocks and watches.

Wood construction technology in architecture had reached a peak at this time. The 67 meter Ying county wood pagoda in Shanxi province built in 1056 is still in good conditions at the present time. The carpenters adopted a technique called "dougong" to maximize the contact area and minimize the pressure on the column, at the same time shortening the crossbeam span and minimizing the bending force. There were over 50 different forms of dougong in the Ying county wood pagoda in Shanxi province. In the early period during the North Sung dynasty when carpenter Yu Hao built the Kai Bao Pagoda in Kaifeng, he deliberately built the pagoda in such a way that it slightly tilted to the northwest with the reason that, since the "northwestern wind prevails due to the openness and lack of hills, the pagoda would become upright when being blown on for hundred years" [1]. Yu Hao ingeniously took into consideration the long term wind effect on structures which made the structures sag unevenly. In building the Mong Tian Pagoda in Hangzhou, he pointed out that the pagoda would be as stable as a box when each and every layer of board was nailed together. The book "Models and Guide to Constructions" written by Li Je (1035-1110) in 1103 which contained 36 volumes including 6 volumes of illustrations systematically summarized architectural experience through periods and dynasties, and handed down to us rich historical information on statics and material strength.

In volume 6 of his "Summaries of Armament," Zeng Gong-Lian wrote: "Wherever a water source is separated by mountains, thick bamboo sticks are to be gathered and their nodes hollowed out; sticks are to be connected in male-female fashion and clay and wax are to be applied to the joint, making sure it does not leak; one end of the pipe is submerged five feet in the water; the other end is heated by burning wood or hay and as a result, the water is seen going uphill." Because of vacuum water pump application similar to this, more and more people investigated the principle behind it. Besides mentioning the related discoveries by Wang Bing in the Tang dynasty (dates of birth and death unknown) wrote in his "Conversations on a Mat:" "I saw the following demonstration by a priest when I was a child; burning paper is thrown into an empty jar which is immediately turned upside down on a silver pan. All of the water will rush into the jar and the silver pan clangs loud and clear - this is caused by the heated air. The same process

is repeated with the silver pan placed on a man's abdomen, and the jar can be lifted without dropping the silver pan. This is similar to the hole in the copper tube - water will not leak when the hole is covered with the finger; and water will leak when the finger is removed." Persons like Zeng Gong-Lian, Yu Yian and others both conceded that the contributing factor in the above experiments was whether there was "air" in the jar/tube. The conclusion "nature abhors a vacuum" is absent in the thinking of ancient physics in China.

In an early stage the ancient Chinese discovered as well as utilized fluid buoyancy. Zeng Yai-Bing (dates of birth and death unknown) one in the third year of the Zhi Ping Era in the Sung dynasty (1066) recovered the ten thousand pound iron bull that fell into a river by using floating boats. "Fill two large boats with dirt and tie the bull in between. Use a thick log as a balance. Secure the bull. The boats will raise and the bull will emerge when the dirt is removed" [2]. This is the earliest application of the principle of the modern weight-lifting float boat.

There are two important discoveries related to fluid mechanics during this period, one of which is the measuring of salt water concentration or specific weight using lotus seed, egg or peach kernel. Song Zan-Ning (918-999) wrote in his "Response Among Matters:" 'Lotus seed will float when it is dropped on a solution of good quality salt.' In his "Sayings on the West Stream," Yiao Huan of the Sung dynasty documented the fact that the above objects would exhibit different buoyancy status in salt water of different concentrations. In his "Water Waves and Floating," Chen Chen (dates of birth and death unknown) of the Yuan dynasty stated that lotus seeds were initially submerged in four different salt solutions whose concentration was known (the most salty; three parts salt to one part water; half salt - half water; one part salt and three parts water), then these four lotus seeds were dropped in salt water whose concentration is unknown; and the salt water concentration could be determined by observing the buoyancy states of each lotus seed. The second important discovery was the invention of the device for demonstrating surface tension. In his "Witness of a Traveling Official," Zhang Shi-Nan (dates of birth and death unknown) of the Sung dynasty said that the quality of tung oil could be judged by dipping into the oil using a thin bamboo strip with one end bent into a circle; for high quality tung oil, a thin oil

membrane would form in the bamboo circle; however, oil membranes failed to attach to the bamboo circle if there were impurities in the tung oil. Nowadays a device used to demonstrate surface tension to students is also a steel wire with one end bent into a circle.

As early as in the Han dynasty, the phenomenon of high tides and ebbs drew attention from the people. Folks tended to investigate the cause from long distance objects such as the moon or the sun. Individuals in the Tang dynasty such as Feng Yian and Dou Shu-Mong not only gave the explanation of the relation between tides and the moon, but also constructed a tide forecast chart. The Sung dynasty is a prosperous period for the study of tides and ebbs, with over twenty relevant documents. Yian Su pointed out that the tide would be at its highest when the moon passed the meridian at midnight or at noon; the tide was on its lowest when the moon passed the meridian around 5-7 AM or 5-7 PM. Yu Qing (1000-1064) pointed out that the morning tide was strong during spring and summer, and evening tide would be strong in fall and winter time. Zhang Jun-Fan (approximately Yian Su's contemporary) derived the time of the daily delay between two tides cycles to be "3 ke 36 fen 3 miao" (equivalent to 48.39 minutes). Based on that there were 30 days in a month and 24 hours was held over one month, the high tide hour would just complete one cycle on the first day of every lunar month. Through his own observations, Shen Kuo (1031-1095) concluded that "the tide occurs when the moon is at midnight or at noon." Furthermore he was the first to mention the relation between high tide hour and the observation location: "To obtain the time of high tide when surveyed at sea, time must be added according to locations which are far from the sea." In the minds of the ancient Chinese, the sun, the moon as well as the omnipresent air and essence of Yin-Yang were interconnected in all respects, therefore they did not think that the super-distance effect of the sun and the moon contributed to the fullness and dispersal of sea water.

Shen Kao did considerable detailed observation on the geometric shape of crystals. He described a sulfuric compound crystal ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) as follows: larger pieces of the crystal had the size of an apricot leaf while small pieces had the size of fish scales and they were all uniformly hexagonal in shape and resembled a turtle shell; angles between crystal joints were long and narrow; the front crystal face had a slight downward slant while the

crystal face on the rear tilted slightly upward; the sequence and overlapping resembled the scales of a pangolin. The crystal had a green color and was transparent on the back. When struck, the crystal would fracture regularly along the grains and even the broken, smaller crystal bore the shape of a hexagon. When heated, the crystal would break apart entirely, falling down like willow tree leaves [3].

In his "Diary Alongside the Stream of Dreams," Shen Kuo recorded a great deal of knowledge on other topics in mechanics. He performed serious observations on the phenomenon of planetary retrograde motion, and in addition, he described their ground paths. He constructed the armillary, the jade jar, the buoyancy leak and the bronze meter. In 1064, after his observation on aerolites, he made the scientific conclusion that aerolites came from celestial iron. He did research on the construction and principle of the crossbow and speculated that higher shooting precision could be achieved if the aiming mechanism of the crossbow was scaled.

LIGHT

In the area of light, Shen Kuo also performed a great deal of observation and experiment. He was the first to use experiments on analogy to prove and demonstrate the scientific reason behind various phases of the moon. He said: "It is like a small ball, half of which is chalked with powder. The part that has been chalked will appear as a hook when the ball is viewed from the side; however, it will appear a full circle when viewed from the front [4]. He also summarized the cause of eclipses of the sun and lunar eclipses. In addition, he observed rainbows and agreed with the opinion of the contemporary astronomer Sun Si-Gong (dates of birth and death unknown): "Rainbows are images in the rain; rainbows are formed when the sun shines on the rain." Shen Kuo documented the phenomena of two cold lights: one was the luminescence of natural chemicals and the other one was luminescence from micro-organisms. Nevertheless, his major contribution on light is in his studies of various mirrors.

In research on speculum mirrors, Shen Kuo proved the basic property that light traveled in a straight line by using the most common needle-hole-image experiment, and at the same time, he explained the inverted images of

buildings and pagodas. Observation on concave mirrors such as the speculum mirrors led him to the discovery of focus. "At a distance of one or two inches from the mirror, the light converges to a dot about the size of a spot." Calling the focus "ai" he rendered a correct presentation of the image formation principle of concave mirrors. The research on reflecting mirrors led him to arrive at the scientific reason that "plane mirrors give large images while convex mirrors give small images" because "a small mirror cannot accommodate the entire face of a person, therefore, the mirror is made slightly convex to hold the entire face of a person in a smaller image" [5]. In addition, Shen Kuo investigated the manufacturing technique and principle of the light transparent mirror. He said: "In the process of forging, the thinner parts cool first while the thick grains on the back cool later resulting in the shrinking of more copper. The design which is on the back still shows up as a vague trace on the side of the mirror and thus is visible under the sun." Shen Kuo's explanation indicated that the thickness of the entire mirror was uneven because of the design on the back; and during the forging process thinner parts cooled faster while thicker parts cooled slower, forming a tiny relief on the mirror front which was identical with the design on the back, and this relief design would be visible when the mirror reflected light. His explanation was logical and reasonable. Nowadays there are three techniques in the construction of the light transparent mirror: 1. Imbedding technique. Brass or red copper is imbedded in the bronze object, a layer of mercury is applied after polishing, and the mirror can reflect the imbedded design. 2. Rolling and scraping technique. After polishing, rolling pressure is applied to both sides of the mirror so that a slight relief grain identical to that on the mirror back is formed on the front of the mirror. 3. Heat treatment technique. The forged mirror is heated for several minutes and tempered by dipping in water and then polished. In the past few years, both the Shanghai Fudan University and Shanghai Communication University were successful in reproducing the light transparent mirror.

In this period slide shows and image shows were rather popular. Cu Yiong (dates of birth and death unknown) of the Sung dynasty referred to a slide show as an "image transferring technique." He documented in detail the related presentation method: "A picture is hidden on a mirror and a lamp is placed nearby. The image will be formed on a paper and such a technique is employed in many places recently" [6]. It is nothing but drawing a

picture on the mirror and the light being reflected. During the Ren Zong era in the Sung dynasty (1023-1063), "There are folks in the market place who can narrate the stories of the Three Kingdoms; or make silhouettes representing the figures in wars among the Wei, Shu and Wu" [7]. This is equivalent to the present combination of two art forms - story telling and shadow play. Undoubtedly the related invention in the Han dynasty is the forerunner of modern movies.

Another aspect of the applied science of light which deserves our attention is the fact that man drew using phosphorus. The ox in the picture appeared to be grazing outside the fence when it was viewed during the day but appeared lying down inside the fence when the picture was viewed at night. Zan Ning, the priest (918-999), explained that after the ebbside, southern people would pick clams on beaches and painted pictures using the fluid from the clams, and such pictures were visible at night but were invisible during the day. Drawings constructed using water mixed with the powder of rocks from the Wo Jiao Mountain were invisible in the day but became visible at night [8]. Apparently the latter is some kind of graphite and it is of no surprise. As an explanation for the former phenomenon, western scientist John Canton in fact mentioned in 1768 a phosphorus from clams which was capable of emitting phosphorescence when certain other substances were added.

In his "New Book on Phenomena," Zhao You-Qin of the Southern Sung dynasty described a large scale optical experiment pertaining to pin-hole image formation. By such an experiment, he not only proved the straight traveling of light but also correctly stated the relations among the light source (size, intensity), distance between the source and the pin-hole (size), and the image (size, visibility).

Knowledge of chromatic dispersion developed in this period. The chromatic dispersion phenomenon of crystals was documented in many ancient books. People got to know quartz as "having bright circles of multiple colors when shown on by the sun. It is hexagonal. Larger pieces with the size of a date or chestnut have lesser brilliance; smaller pieces with the size of a pearl have pleasantly bright multiple colors" [9]. In addition there was the "myna bird eye" which "is exactly like the eye from the real bird, and it

has multiple halos and the color is green" [10]. Lu Dian (1042-1102) once performed a chromatic dispersion experiment on a rainbow. He said: "Rainbows are born when the sun shines on rain drops. Water is sprayed from my mouth against the sun, and as I view it on the side, the halo becomes a rainbow. Therefore a rainbow is formed on rain vapor and it is in the west when shone on by the morning sun, and it is in the east when shone by the afternoon sun: [11]. Cheng Da-Chang (1128-1195) rendered an in-depth description of the chromatic dispersion phenomenon of dew drops: "There they are - on grass, tree branches and leaves, usually after a rain or before the dew is gone. Hanging there in a semi-dropping condition, they all appear to converge in round spheres and are delightfully bright and clear. Many colors are displayed and they glitter when sunlight lands on them. It is the revelation of the colors of sunlight in water; the rain drops themselves do not possess such multiple colors" [12]. Here Cheng Da-Chang not only documented the rain drops' surface tension phenomenon, but also more importantly he documented the phenomenon in which sunlight was dispersed into various colors by dew drops. However, limited by scientific conditions and scientific thinking, he was unaware of the significance of this discovery. This is one of the examples where a scientific discovery cannot possibly be realized when it is well ahead of the time. It was not until 1666 when Newton experimented with the prism that the conclusion that sunlight (white light) consists of various lights of different refraction indices was arrived at.

LIGHT

After his studies on the shape of the ancient musical bell, Shen Kuo analyzed its acoustic effect. According to him, the sound of the circular bell was long and humming and interference occurred in fast rhythm and consequently a melody failed to be formed, while the sound from the cowbells (with oval cross-section) is short and usable in playing melodies. This is the reason why ancient folk cast their bells in an oval shape. Shen Kuo's analysis met real situations. Lord Rayleigh (1842-1919) in the last century performed an analysis on round bells in European churches to reveal acoustically the fact that there were many vibration modes from round bells in which multiple sound, long humming and great interference existed. Such an analysis prompted people in the first half of this century to doubt the performing

capability of metal bells. In 1978, in the Sui county of Hupei province, archaeologists unearthed a set (65) of Zeng Ho Yi bells of the Warring States Period whose musical range spanned five octaves. This set of chime bells was in reality used in musical performance, furthermore they were capable of giving out two fundamental tones of different frequencies at two locations. It can be expected that the ancient Chinese chime bell was the oldest metal bell class instrument that had the capacity to be developed further.

In addition Shen Kuo discovered the resonance of a tube and a string. He discovered that two sound sources of multiple and simple integer ratio would produce resonance. He used paper dice to experiment and prove the resonance phenomenon as follows. "In order to tell if a sound source will respond, its string has to be tuned so that harmony is achieved, then cut a paper figure and place it on the string. The paper figure will vibrate at the sounding of the respondent string while other strings remain stationary" [13].

Around the second half of the 12th century, Zhao Xi-Gu (dates of birth and death unknown) of the early Southern Sung dynasty investigated acoustic technique problems on musical instruments such as the ancient string instruments. In his "Dong Tian Document" he described the relation between the tung wood construction with which the string instrument is made and its sound. "The tung wood should not be porous. Sound from instruments made with porous and loose-grained tung wood is flat and empty. Solid tung wood with a close and straight grain should be chosen. And it should not leave any indentation when a fingernail is poked against it." He also noticed that there were two sides to the tung wood - the Yin side and the Yang side. String instruments made with different sides from the same piece of tung wood would display different acoustic effects. He was very critical in the technical details in constructing string instruments, such as the selection and installation of the material for the string instrument base, and he also explained the acoustic reason behind such techniques. He suggested to build a "room for playing string instruments" in order to have the bass sounding ancient string instrument achieve a higher volume. For the design of this ancient music conservatory, he wrote: "Solidity is more desirable than emptiness. The ground floor of a multi-story building is preferred, because the sound will not disperse due to the existence of floors above while the openness and

and quietness below will enhance the clearness of the sound. The sound will become diffused in high halls or big mansions, whereas the sound will fail to propagate in small enclosed rooms; and places such as gardens and pavilions are the least desirable."

ELECTRICITY AND MAGNETISM

The science of magnetism reached a peak in its ancient stage. Shen Kuo and Kou Zong-Shong of the Northern Sung mentioned a method of artificial magnetization: iron needles would be magnetized if rubbed against natural magnets. The method of magnetization employed by Zeng Gong-Lian in the construction of the south-pointing fish was : "A 2" X $\frac{1}{2}$ " fish-shaped piece is cut from an iron sheet and heated until red. Secure the head of the fish with a pair of tongs and take the fish out of the fire with its tail facing north. Submerge the fish in a pan of water in such a way that the distance between the tail and the water surface is about half an inch. Keep the fish in an enclosure" [14]. Here in the instructions, the purpose of heating is to resolve the irregular orientation of the magnetic domain in the iron; quenching can cause a change in the iron so that magnetic permanency can be maintained; "with its tail facing north" means placing the iron fish in the south-north direction in earth's magnetic field so that the magnetic domain can be oriented, and at the same time, higher heat residual magnetism can be gained due to the closeness to earth's magnetic field firection; in the process of quenching the purpose of "submerging the fish in a pan of water in such a way that the distance between the tail and the water surface is about half an inch" is to allow the iron fish to form a slanted orientation and better magnetism can be achieved considering the magnetic dip.

Shen Kuo was also the first person to discover the earth's magnetic declination: "Needles magnetized by rubbing with a magnet are capable of pointing to the south, however, they tend to be slightly biased to the east and do not exactly point to the south" [15].

The south-pointing needle which had a vital impact on world civilization is a great invention of our ancestors. Shen Kuo pointed out four ways to install the south-pointing needle. 1. Floating technique, in which the needle is placed on water; 2. Nail technique, in which the needle is placed

on a smooth nail; 3. Bowl rim technique, in which the needle is placed on the rim of a bowl; 4. Silk hanging technique, in which a silk thread is tied at the middle of the needle and the needle is hung. Kou Zong-Shong showed in detail that for the floating technique several rushes were first pierced with the south-pointing needle and then placed on water by means of their buoyancy. In the chapter 'Fairy Magic' in his book "Chronicle," Chen Yuan-Qing of the Sung dynasty (dates of birth and death unknown) documented two kinds of south-pointing needle - south-pointing fish and south-pointing turtle. For the former case, the needle was placed in a piece of wood shaped like a fish which floated on water; in the latter case the needle was placed in a piece of turtle-shaped wood and a bamboo nail was used as the turning pivot. The silk hanging technique and south-pointing turtle were the forerunners of the dry compass, while the other techniques developed into the hydraulic compass in later times.

Furthermore our nation was again the earliest to apply the south-pointing needle in navigation. In his "Topics on Ping Zhou," Zhu Yu of the Sung dynasty documented in 1119 the south-pointing needle used in navigation as follows. "The boat masters understand geography. At night they refer to the stars, during the day they refer to the sun, and when it is cloudy and dark they would refer to the south-pointing needle." Xu Jing (1093-1155) gave similar notes in his "Missionary Trip to Korea." Thus it is obvious that in the early 12th century the south-pointing needle was extensively used in navigation by the Chinese. According to what was recorded in the "Mong Liang Diary: by Wu Zi-Mu of the Southern Sung, on windy, rainy or cloudy days "the boat navigated only by the compass" and "dared not make the slightest error since it is a matter related to all the lives on the boat." Since the time of the Southern Sung dynasty, because the compass was used in navigation, "needle-routes" meaning the connection lines between different needle locations on a navigation course, were documented in ancient books in the late 13th century. The Chinese south-pointing needle was channeled to Arabia by sea around the late 12th century and early 13th century, and then propagated from Arabia to Europe.

In the area of electricity, Shen Kuo had an important observation. He observed that in the two incidents in which the home of an imperial palace

official Li Xin-Ju were struck by lightning, metal substances (such as silver buckles on boxes, swords inside their scabbards) along the electric path were all melted whereas the boxes and leather were safe [16]. Inspired by the record of Kuo's observation, Zhuang Chao (dates of birth and death unknown) observed a similar phenomenon in the early Southern Sung dynasty: lightning destroyed the Buddha statue in the Pu Yian Temple in Nan Xiong Zhou; metallic colors covering the statue were all melted while other colors remained untouched [17]. Ever since that time many related records prompted man to arrive at the conclusion that metal objects had different properties from lacquered utensils. And this is exactly the early stage of the concept of conductivity and insulation in modern day electricity.

MING AND CHING (1368-1911)

This era was behind the West in the development of science as a whole, including physics.

MECHANICS

The major achievement in mechanics is evidenced by the book "Tian Gong Kai Wu" by Song Ying-Xin (1587-?). Being the world's earliest encyclopedia on production technology of agriculture and handicraft, it is an extraordinarily important work of the world's scientific technology in the 17th century. In stating that the string on a bow was so powerful and yet it did not damage the crossbow stem, the book explained that cowhide or soft wood was glued to both ends of the crossbow stem which was conventionally known as a "string pad;" thus "the returning force from the string is stopped right there, otherwise the bow would have been damaged." It documented the method for gauging the power of a bow: "place a foot on the string and press it onto the ground, and place the hook of a balance at the middle of the bow. As the string is pulled fully, the measurement is known by whatever the weight indicates" [18]. Song Ying-Xin pointed out that the feather on an arrow was extremely vital in guaranteeing the precision of the arrow's trajectory. In chapter nine, "Vehicles," of the book, the significance of the ratio between the sail and a boat's length was stated as follows: "The size of a sail is determined with respect to the width of the boat. It will be detrimental if the sail size is excessive, while underpowered if the sail

size is too small." In addition, the relation between the height of a sail and the force it would be subject to was discussed. The relation among side-ward wind direction, travel direction and the orientation of the sail was analyzed in detail. Furthermore the book documented the effect of a helm's length on its power as well as the effect of a helm's orientation on the direction of a boat's movement.

As in the area of machinery and instrument construction, Zhang Xi-Yuan (dates of birth and death unknown) of the Ming dynasty built the five-wheel-sand-leaking machine in the early 16th century which was powered by the weight of sand. Among the five wheels, arrangement of the initial wheel and the four subordinate wheels already bore resemblance to the later clock. Having researched and constructed hydraulic, wind powered and weight machinery in his earlier years, Wang Zheng (1572-1644) wrote a book "Illustrated Documentation on Various New Equipments."

A remarkable note was that during the reigns of Kang Xi and Qian Long in the Ching dynasty, the Ching government organized two large scale geographic surveys. In the one performed from 1708 to 1718, longitudes and latitudes of over 630 locations in the country were surveyed, establishing a longitude - latitude network which centered in Beijing. In this survey, it was decided that the "Chi" construction of the Engineering Bureau was to be the standard; and that 1,800 "Chi" was set to be 1 "Li" and 200 "Li" was equivalent to 1 degree in longitude. Such a scaling system in which the length unit was equated with a degree in longitudinal direction was an innovation in the world, and it is 80 years earlier than the decision of the French Constitutional Conference in which 1/40,000,000 degrees was set to be equal to 1 meter. In the process of actual surveying of the length of 1 degree of longitude, it was discovered that for every longitude its length varied depending on the location on a latitude. This provided information relating to the discovery that the earth is an oval sphere.

The doctrine of air and essence which was instrumental to the thinking of Chinese physics reached a speculative peak in this period. The doctrine of air and essence conceded that the universe as well as all the matter in the world consisted of a kind of "air" which was microscopic and formless

and invisible to the human eye but nevertheless it filled the universe and space. In the conversion of air and essence, all matter was born, and the diversion of all matter would become air and essence. In addition this air was in a state of constant motion. Because of the particle motion of the air and due to the opposition of Yin and Yang in it, the variety of celestial bodies and their motion were thus constituted. Ever after the Chin dynasty, idealistic thinkers throughout the periods, all upheld the doctrine of air and essence. Sung philosopher Zhang Zai (1020-1077) developed the doctrine of air and essence tremendously; Wang Fu-Zi (1619-1692) between the Ming and the Ching dynasties further promoted the doctrine to a peak. Through concrete instances (such as boiling water, heating mercury, etc.) as well as philosophical theory, Wang Fu-Zi proved that matter in the world is constant. According to William P. T. Martin (1872-1916), a late Ching priest, the Chinese doctrine of air and essence had influenced R. Descartes in his proposal of the eddy theory.

LIGHT

Fang Yi-Zhi of the late Ming dynasty summarized his predecessors' documentation on the phenomenon of chromatic dispersion. "Light will form in a ray on convex gems. For gems of many sides, one of the sides will display multiple colors, for example, the hexagonal shining rock Er-Mei, the triangular quartz. Multiple colors are also displayed on a waterfall in the sun, as well as in the water sprayed from a man's mouth between walls. Therefore, it can be concluded that the same reason is behind the color on a rainbow, the halo around stars and the moon, and a colorful cloud" [19].

Several optical instrument designers emerged in the Ching dynasty: Huang Li-Zhuang (1656-?), Sun Yun-Ciu (approx. first half of the 17th century), Huang Li (female, later 18th century - early 19th century) and Zou Bai-Ci (1819-1869). Huang Li-Zhuang invented the world's earliest spotlight ("auspicious light mirror"). Being an optician among the masses in our nation, Sun Yun-Ciu made his living manufacturing eye glasses, and independently constructed the "thousand-mile-eye" (unknown), "eye-keeping lens" (magnifying lens), "lens for viewing micros" (microscope), "thousand flowers mirror" (kaleidoscope), "illusion mirror," and so on. It is a pity that his book "History of Mirrors and Lenses" was lost. Huang Li once constructed the "thousand-mile

lens" (probably similar to the present day's astronomical camera) which was used in photographing objects at a distance of several miles. The following are mirrors constructed by Zou Ba-Ci: Refraction telescope in which he used a group of convex lenses with different focal lengths to eliminate chromatism; "Returning light mirror" - a reflection telescope made with concave mirror and lenses; "Observation instrument" - also a telescope; "Image-capturing device" - a simple camera. Zou Bai-Ci successfully analyzed photography, and he prescribed the sensitizer, the developer and the fixer. He performed analysis of geometric optics and proceeded with experiments, and he wrote theses on optics such as the "Investigation Technique" and "Image-capturing Instruments." Though influenced to a certain degree by western science, nevertheless a good portion of the work was his own innovation.

Zeng Fu-Guang (1780-) was another optician of this period. Published in 1847, his book "Mirrors and Mirrors of Fantasies" was a relatively systematic work on optics in our country, was well as a work that embraced the best of optics in our country. In the theory of image formation, Zheng Fu-Guang attentively portrayed the principle of image formation, laws of the light path and computation schemes in such a way that "the analysis and logic were so concise and intriguing that the book is capable of inspiring ones who are yet to be born" [20]. Though in the area of the light path, Zheng Fu-Guang was misled by the book "Telescopes" by the western priest Jean Adam Schall von Vell, the image locations and directions of various lenses were all correct. Thus it is obvious that Zheng Fu-Guang's work on optics was based on his respect for experimental facts.

HEAT

Wen Zhen-Heng (1585-1645) of the Ming dynasty pointed out that as far as fire insulation material was concerned, asbestos was the best and metals such as gold and silver were not to be used [21]. In the chapter entitled "Pottery" in "Tian Gong Kai Wu," Song Ying-Xin gave a detailed record of heating technology in the manufacturing of pottery and ceramics. He wrote: "There are two kinds of brick kilns - one using wood and the other using charcoal. Bricks fired in a wood-heated kiln have a blackish green color while those fired in a charcoal-heated kiln have a white color. Three holes are

opened on the top near a wall of a kiln for venting the smoke and are sealed tight as soon as there is sufficient wood. Thereafter, the clay is dried. As far as the heating time is concerned, the bricks would not have a luster if the heating time is too short by one time unit; they would display their original colors and would break apart when exposed to frost and snow; later if the heating time is short by three units of time, they form grains and and cracks if the heating time is one unit too much; would shrink and bend and not be useable if the heating time is three units too much." "Firing temperature is inspected through the door of the kiln. As the clay is heated by fire, the hot air and vapor dances in such a way that it resembles the melted state of a metal." In the chapter "Forging," Song Ying-Xin also recorded the method of cold forging.

SOUND

Zhuang Yuan-Chen (dates of birth and death unknown) of the Ming dynasty clearly stated the thinking of "sound causing vibration in air." Song Ying-Xin explicitly indicated that the vibration of "air" that carried sound propagation was analogous to water waves. In the area of acoustic technology, the sound-proofing technique was discovered in which urns were used in the construction of a wall in such a way that their openings face outside [22]. In the eighteenth year of the Yong Le Era in the Ming dynasty (1420), the Temple of Heaven, famous in the world today as in the past, was built. The Echo Wall, the Triple Sounding Rock and the Circular Hill in the Temple have fascinating acoustic effects.

In the area of music, Zhu Zai-Yu (1536-1614 approximately) of the Ming dynasty used a progression with a common ratio of $^{12}\sqrt{2}$ in the distribution of musical notes, making the frequency ratio between any of the two adjacent notes equal to $^{12}\sqrt{2}$ or 100 divisions in a major, and finally completed the twelve even tones in 1584. This revolutionized the field of music and it was a major contribution in the history of sound in the world.

ELECTRICITY AND MAGNETISM

Marine navigation in the Ming dynasty was prosperous and the compass was extensively used in navigation. Navigator Zheng He (otherwise known as

Ma San-Bao) made seven trips on the Pacific Ocean during the Yong Li and Xuan De eras (1405-1433). His fleet passed several times southeast Asia, the Indian Ocean, the Persian Gulf, and reached Kenya and its vicinity on the east coast of Africa, covering voyages of half a million kilometers. Volume 240 in "Armament" bore "the map illustrating sailing from the Bao Chuan Ship Yard through Long Jiang Pass and reaching various foreign countries." The author Mo Yuan-Yi conceded that it was the map used by Zheng He in his navigations. The map recorded the compass direction to and from various places. During the Ming and Ching dynasties, works of compass navigation were abundant in our country, and many books were carried out of China. The Bodleian Library in England's Oxford University has the early Ching "Bon Voyage" and "Guidelines on the Compass," both hand copied editions. The primary content of the books is the documentation of places in the Atlantic and the Pacific Ocean. "Bon Voyage" was completed during the 16th century and "Guidelines on the Compass" was written in the early 18th century.

An important discovery in the science of magnetism in this period was the phenomenon of the magnetic shield. In chapter one in "Miscellanies of Guang Yang" Liu Xian-Ting (1648-1695) wrote: "Magnets attract iron. What can interfere? Answer: 'Only iron can.' The person leaves and then returns and says: 'It is so after I try.'"

In the area of static electricity, Zhang Ju-Zheng (1528-1582) of the Ming dynasty discovered that fur coats as well as beautiful garments could generate electricity when rubbed against human bodies. Du Shi (dates of birth and death unknown), a contemporary of Zhang Ju-Zheng, also documented the electricity generation experiment in which a certain silk fabric was rubbed. The Wu silk generates sparks. Sparks will be produced when hands rub against garments made of Wu silk for a long period of time, and such sparks are visible in a dark room"[23].

THE PROPAGATION OF MODERN PHYSICS IN CHINA (1600-1910)

The propagation of modern physics in China can be divided into two periods. The first period of over 100 years is the period from the end of the Ming dynasty to the early Ching dynasty, i.e. from the late 16th century

to the late 17th century. The second period is from the Opium War (1840) to the end of the Ching dynasty. During the times when both European and American priests came to China, to use education as a means to conduct evangelical activities, as a result, portions of the West's scientific works were translated, and it was by these translations that modern physics was channeled into China.

The first period is a 100 year period of the building of mechanics which commenced from Galileo's study of falling objects (starting in 1589) to Newton's publishing the "Mathematical Principles of Natural Philosophy" (1687). The following are the major translated works related to physics.

"Illustrated Documentation of the Wonderful Equipments from the Far West" was a book written by Wang Zheng (1572-1644) from the dictation by Johannes Terrenz (a German, 1576 to 1630, came to China in 1621). The primary content of this book is statics, such as simple machinery, and its combined utilization. Certain individual topics might originate from the book "Mechanics" (1600) and "The Behavior of Objects on Fluids" (1621) by Galileo. However, the name of Galileo who was the founding father of modern mechanics was never mentioned.

"Documentation of Instruments" was a book written by Ferdinand Verbiest in 1664 (a Belgian, 1623 to 1688, came to China in 1659). Volume two entitled "The Principle of the Strength of New Instruments" dealt with material science; in addition, a good portion of its content originated from the book "Dialogue on the Two New Sciences" published by Galileo in 1638. Volume four "The Pendulum" introduced the constant time property of the single pendulum and the inverse proportion law of pendulum length and cycle - discoveries by Galileo.

Jean Adam Schall von Bell (a German, 1591 to 1661, came to China in 1622) wrote "Telescopes" in 1626. Published in 1630, the book was proofread by Xu Chao-Jun and edited by Wu Shen-Lan. This book introduced the manufacturing technique of the telescope and contained a sketch of the telescope used by Galileo in earlier days, and documented the celestial picture observed by Galileo using the telescope: valleys in the moon, the reduction and expansion changes of Venus, the four satellites of Jupiter, Saturn's ring and

the sun's black spots. There were a dozen sketches; however, the diagrams of image formation of concave/convex lenses were all wrong, therefore, it had very little value in optical science. This indicated that Jean Adam Schall von Bell himself did not understand optics, he merely introduced to China what he heard in western Europe. His erroneous diagram of light travel had influence on Zheng Fu-Guang later.

The knowledge of modern physics channeled into China during the first period was nothing but bits and pieces. During the second period, more knowledge of modern physics was introduced to China in the form of translated works, and Li Shan-Lan (1810-1882) made an outstanding contribution in this area.

A book entitled "The Study of Weight" (Mechanics) which was translated by Li Shan-Lan from dictation by Joseph Edkins (an Englishman, 1823 to 1905, came to China in 1848) introduced in a relatively systematic manner classical mechanics to China. The original edition was a book entitled "An Elementary Treatise on Mechanics" by W. Whewell (1794-1866) in 1858. The translated version, "The Study of Weight," was published in 1858 and 1860. In the book "Celestial Discussion" - a joint translation by Li Shan-Lan and Alexander Wylie (an Englishman, 1815 to 1887, came to China in 1847), the knowledge of universal gravitation and celestial mechanics was introduced to China the first time. The original edition of "Celestial Discussion" was "Outline of Astronomy" by John F. W. Herschel (1792-1871). Soon afterward, Li Shan-Lan began to translate "The Mathematical Principle of Natural Philosophy" by Newton but the work was interrupted when one-third completed.

"Discussion of Light" which was initially translated in 1853 by Zhang Fu-Xi was a book that brought the knowledge of modern optics to China in the earliest days. Starting from the 80's in the 19th century, there had been a noticeable increase in translated works of physics, among which were the following books of relative significance: in the area of mechanics - "Illustrated Study of Weight" (1885), "Investigation, Survey and Calculation on Matter" (1883), "Algorithm of Physics" (1904); in the area of optics - "Genuine Recording of Images" (1877), "Illustrated Study of Optics" (1890), "Camera" and "Microscopes and Telescopes" and so on; in the area of heat, "Matter's Changes When Heated" (1899), "Illustrated Study of Heat" (1890); in the area

of electricity, "Electricity" (1880), "Illustrated Electricity" (1887), "The Essence of Electricity" (1899).

It was not until 1900 that there were specialized books which called physics "physics" (please refer to the section on the evolution of the term "wu li"). The following is a list of translated books that were of relative value. "Acoustics" translated by Xu Jian Yian in 1874 was based on the first edition of a book bearing the same title by an English physicist named John Tyndall. Among all translated works, the most up-to-date book was "Penetrating Electric Light" (X-ray). X-rays were discovered by Roentgen in 1895 and four years later the Chinese copy whose translation was done by Fan Xi-Yong was published. Although the application of radio technology had just begun in 1900, this book covered virtually all the related theories and concepts.

Among the many translated works of physics which were channeled into China, except for some books that were of relatively high value, the majority were textbooks of junior high school level. Furthermore, due to the lack of physics knowledge of the priests themselves, such translated works were usually in pieces and segments, and many of the books were repetitious in content. With the Chinese's gradual popularization of modern scientific knowledge, a large number of translated work in physics which were of higher quality and translated independently by Chinese began to emerge in the first half of this century. And at that time, with the increase in the number of students studying physics abroad, the Chinese were also entering the world's garden of physics; however, this is the period that belongs to the history of physics in this century and it will be discussed later.

Due to the limitation of space, only a skeleton of the topic has been addressed by this article, and there will surely be omissions and over-simplification. Corrections from the reader are welcome. Special thanks are expressed here to Mr. Wian Lin-Zhao for his advice on this paper.

FOOTNOTES

1. "Diary Alongside the Stream of Dreams."
2. "History of Sung," Volume 462.
3. "Diary Alongside the Stream of Dreams," Volume 26.
4. "Diary Alongside the Stream of Dreams," Volume 7.
5. "Diary Alongside the Stream of Dreams," Volume 19.
6. "Perplexity."
7. Gao Cheng, "Documentation of Miscellaneous Events and Matters."
8. Zeng Wen-Yin of the Sung dynasty, "Documentation of Xiang Shan;" Zhou Hui, "Diary on the Miscellanies on the Tranquil Hills."
9. Du Ji-Yang, "Documentation of Rocks," First Volume.
10. Zhu Yu, "Discussion Topics of Ping Zhou," Volume 3.
11. "Elegance," Volume 20.
12. "Dews."
13. "Supplementary Discussion," Volume 1.
14. "Summaries of Armament," First Volume.
15. "Diary Alongside the Stream of Dreams," Volume 24.
16. "Diary Alongside the Stream of Dreams," Volume 20.
17. "Chicken Wing."
18. "Excellent Armament."
19. "Wu Li Knowledge," Volume 8.
20. Zhang Fu-Xi, "Optics," chapter on "Foreword."
21. "Documentation of Substances," Volume 7.
22. "Wu Li Knowledge," Volume 1.
23. "Diary by San Yu."

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